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IS MARS SAMPLE RETURN REQUIRED PRIOR TO SENDING HUMANS TO MARS?

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Prior to potentially sending humans to the surface of Mars, it is fundamentally important to return samples from Mars. Analysis in Earth's extensive scientific laboratories would significantly reduce the risk of human Mars exploration and would also support the science and engineering decisions relating to the Mars human flight architecture. The importance of measurements of any returned Mars samples range from critical to desirable, and in all cases these samples will enhance our understanding of the Martian environment before potentially sending humans to that alien locale. For example, Mars sample return (MSR) could yield information that would enable human exploration related to 1) enabling forward and back planetary protection, 2) characterizing properties of Martian materials relevant for in situ resource utilization (ISRU), 3) assessing any toxicity of Martian materials with respect to human health and performance, and 4) identifying information related to engineering surface hazards such as the corrosive effect of the Martian environment. In addition, MSR would be engineering 'proof of concept' for a potential round trip human mission to the planet, and a potential model for international Mars exploration.

I. INTRODUCTION

Return of samples from Mars has long been a high priority scientific goal of Mars exploration as an essential complement to an on-going exploration strategy of remote sensing and *in situ* investigations (1). In situ and remote sensing measurements have provided many key insights into these science questions, but certain measurements such as precise radiometric age dating, sophisticated stable isotope analyses, a complete toxicology assay of martian materials, and definitive life detection assays are currently not possible without returned samples in Earth laboratories (2). In addition, only a limited number of predetermined measurements can be made with remote missions. In contrast, with samples in hand, the full analytical capabilities of terrestrial laboratories could be utilized to address such critical issues as climate history, geologic evolution and the search for life on Mars. Furthermore, the analytical approach could be both *comprehensive* and *adaptive* with the analytical strategy changing as more is learned about Mars through the returned samples. As demonstrated with Apollo samples, new techniques enable new measurements decades after sample return.

In addition to addressing high priority scientific questions, here we argue that sample return is a critical

step towards enabling and enhancing potential human missions to Mars. With samples here on Earth, essential health and safety information on potential hazards, both toxic and biologic, could be confidently assessed; utilization of potential resources to sustain human exploration could be based and tested on actual samples; and the corrosive effects of the near surface materials could be judged. In addition, Mars sample return would be engineering 'proof of concept' for a round trip human mission to the planet, and a potential model for international Mars exploration.

In support of MSR as a desirable, if not critical, mission prerequisite for the potential human exploration of Mars, we present an overview of the precursor investigations enabled by sample return. Specifically, sample return is relevant to a very diverse range of investigations in preparation for any human mission to Mars. These can be roughly grouped under five themes: Life and Biohazards, Resources, Atmosphere, Human Factors, and Surface Hazards. The types of analyses of interest and their importance vary from theme to theme.

II. LIFE AND BIOHAZARDS

The search for life has long been the focus of the scientific exploration of Mars (3). In addition to the intrinsic science merit of searching for life on Mars, this

search is also relevant for enabling human exploration. Prior to potentially sending humans to Mars we must determine whether or not indigenous martian life forms exist to 1) understand the potential biologic risk to human life and 2) develop an exploration strategy that is scientifically and ethically compatible with the presence of martian life should it exist. These issues form the crux of planetary protection concerns regarding human exploration of Mars. We note that although the presence of extinct life is scientifically important, the possible presence of extant life is most relevant from a planetary protection perspective.

Planetary protection is of importance because of all the bodies in the solar system other than Earth, arguably Mars is the most likely to have harbored past and/or present life. Mars is a prime target for the search for life beyond Earth due to the overwhelming evidence of past liquid water flowing on the martian surface as well as indications of possible liquid water activity in geologically recent times. Mars also possesses a thin atmosphere containing carbon and nitrogen, two essential ingredients for life as we know it.

Early Mars and early Earth likely shared similar warm and wet conditions. There is evidence of life on Earth shortly after the period of intense comet and meteor bombardment following planet formation. Therefore it is possible that life also existed on Mars during this same time period. If life began on (or was transported to/from) Mars during this time period then this life could have survived in hospitable niches to the present day, perhaps episodically reviving near the surface when the necessary conditions occur. Given the possibility for life on Mars, a positive finding would have revolutionary consequences for science and humanity. In this search, life detection, planetary protection and biohazard assessment are the same concept.

Water is essential for life as we know it and likely exists on Mars today in several different settings. Both permanent polar caps contain extensive regions of water ice exposed at the surface. They are also both primarily composed of water ice (mixed with small to moderate amounts of dust). The Gamma Ray Spectrometer (GRS) instrument aboard the Mars Odyssey spacecraft has detected water ice, where high latitude regions tend to have 50% water ice by volume within the upper meter of the subsurface. Ice is also likely present in the mid-latitude near-surface environment in the form of rock glaciers, mantle deposits, lobate debris aprons, and lineated valley fill. Geothermal or climatic warming of such deposits could provide temporary havens for life. There are also tantalizing indications of recent water erosion on the martian surface in the form of gullies (4). Gullies forming in the mid- to high latitudes in both hemispheres have been attributed to flowing water. Recent HiRISE data show that currently active gullies

appear to be active in the winter season. In particular, activity appears to be constrained to occur when the terrain is covered in seasonal CO₂ frost (45). Recurring slope lineae (RSL) are also evidence of probable recent water or brine activity (6). The RSL may form on sun-facing slopes and become active during the warmest months of the year. The RSL are hypothesized to form from melting of near-surface ground ice and hence may be indicative of liquid water activity on the martian surface. Groundwater may also have been recently brought to the surface. On somewhat longer time scales – millions of years – liquid water may have resulted from melting of ice deposits at the surface.

Despite these indications of past and present water on Mars, the surface of Mars today is not particularly hospitable to life. The martian surface is dry (except for localized regions of possible water activity), oxidized, and bathed in ultraviolet radiation. Organic molecules are not stable on the surface and the likelihood of life existing there is low. However, conditions just below the surface or within endolithic habitats may provide a more habitable environment where life forms are protected from the surface radiation environment by the overburden of regolith. In addition, habitable conditions may occur locally and temporarily.

Potential human exploration of Mars presents both opportunities and challenges with respect to the possible presence of life on Mars and planetary protection. Human astronauts have unique capabilities that could greatly facilitate the scientific exploration of Mars and in particular the search for life. However, human exploration must adhere to policies regarding both forward and back contamination that are designed to mitigate possible adverse effects to either Earth or Mars. Forward contamination refers to the possible introduction of terrestrial organisms to the martian environment. The main concerns pertaining to forward contamination are scientific (e.g., that we should not contaminate the planet before we have conducted credible searches for evidence of life or prebiotic chemistry and to characterize any existing life forms) and ethical (e.g., that if indigenous martian life is present we should not inadvertently destroy it). Back contamination refers to the possibility of returning martian life to Earth. The main concern of back contamination is that martian life could potentially be harmful to the Earth's biota and any human crew.

Robotic missions address forward contamination issues in several ways such as sterilizing parts that touch the surface, maintaining stringent cleanliness standards, and making assays of the bioburden of any parts that enter the atmosphere and land on the surface. Potential human missions create a much greater risk of forward contamination than robotic missions. Humans carry a diverse range of microbial populations that are necessary for survival. A substantial bio-load would

therefore be taken to the surface and bioassays would be impractical. Despite the best intentions and the best engineering practices, it is inevitable that during extended human stays on the surface some of this bioload would contact the martian surface. The contaminants would then tend to be dispersed away from the landing site by the wind, possibly reaching localities that are more hospitable than the landing site itself. The Committee on Space Research (COSPAR) (see 7) refers to these more hospitable places as special regions, defined as “a region within which a terrestrial organism is likely to replicate” and “any region that is interpreted to have a high potential for the existence of extant martian life forms”. Although landing at zones of minimum biologic risk and avoiding landing near “special regions” would reduce the potential adverse effects of forward contamination, the potential remains that human missions would be much more likely than robotic missions to inadvertently compromise any evidence that might exist for past and/or present life. The potential for past and/or present life on Mars must be assessed before any human missions compromise the evidence. The most credible way to make this assessment would be to return samples to Earth so that the full analytical power of terrestrial laboratories might be used to conduct this scientific investigation. A robotic sampling mission with a rover could sample both special and non-special regions. Once samples returned from places with potential resources such as ice have been assessed, concerns about forward contamination by humans would be substantially alleviated if there proves to be no evidence of life or pre-biotic chemistry. Any positive evidence for life would be a fundamentally important discovery and would be thoroughly assessed as part of the humans-to-Mars enterprise.

Although forward contamination is primarily a science issue, back contamination of Earth is a safety issue. The 1997 Panel on Mars Sample Return (8) concluded that “contamination of Earth by putative martian microorganisms is unlikely to pose a risk of significant impact” but “the risk is not zero” and recommended that any samples returned from Mars by spacecraft should be contained and treated as though potentially hazardous until proven otherwise. Numerous subsequent panels since that time have agreed with these statements and investigated methods for handling returned Mars samples (e.g., 9). For robotic missions the protocols recommended by (9) involve sealing the samples at Mars, breaking the chain of contact with Mars upon leaving the planet, unsealing the samples in a Biosafety Level-4 (BSL-4) facility, performing a wide array of life-detection and biohazard testing on the contained samples, and gradually moving along a de-containment path if the biohazard and life detection tests are all negative. For any human mission

at Mars, such procedures could be followed for the samples intentionally gathered and sealed at Mars. However, for Earth return, the primary concern would be the inadvertent introduction of martian materials, mainly dust and regolith, into the crew living space. These martian materials might come into contact with or be inhaled or ingested by the crew, and it might not be possible to guarantee that the materials make no contact with elements of the terrestrial environment upon Earth return before they are proven to be safe.

The most straightforward way to assess whether martian materials present a risk to a crew or the Earth is to robotically return contained samples of dust and regolith to Earth prior to any human missions, treat the samples as though they were hazardous until proven otherwise and follow procedures for sample handling, life detection and biohazard assessment similar to those outlined in (9). The results of such a mission or missions would then be used to assess how best to handle how any human missions address back contamination issues. In the event that the returned martian samples present no hazard, then back contamination procedures could be relaxed, as was the case with Apollo once lunar samples had been closely examined. If martian life would be detected in the returned samples and it proves to be hazardous, or the martian materials were found to have other adverse effects, then the rationale and architecture of any human missions would have to be re-assessed.

Concerns over forward and back contamination have led to numerous workshops and international agreements on how Mars exploration should be conducted. The work has usually focused on robotic exploration but human missions have also been considered (e.g. 10). The participants in these workshops generally agree that despite stringent controls, human missions would inevitably result in some forward contamination. In addition, any human exploration of Mars would likely result in contamination of the astronauts’ living space and upon their return, some uncontaminated martian materials might be introduced to Earth. Countermeasures that have been proposed to mitigate forward and/or back contamination include landing in zones having minimum biologic risk and assessing potential biologic hazards with precursor missions (including sample return). The strategy to land at sites with minimum biologic risk might reduce some of the planetary protection concerns but it would conflict with other high priority mission objectives. For example, one of the highest priority science objectives for potential human exploration would be to study areas of water activity (liquid water and ice) on Mars to understand climate, geology and the potential for martian life (3). However, these most compelling science sites are deemed off-limits by planetary protection policies (7). Another

example of incompatibility between current planetary protection policy and human exploration relates to ISRU. Water ice potentially could enable human exploration, yet the presence of ice would invalidate a site for human exploration since ice is not a zone of minimal biologic risk. These issues highlight the importance of Mars sample return prior to any human exploration. Sample return would allow us to conduct the most thorough investigation for martian life possible prior to any human exploration in order to develop and implement the most robust and practical planetary protection protocols.

II. RESOURCES

In situ resource utilization on Mars is considered a high-priority enabling technology for any human exploration as it can significantly reduce the quantity of consumables that require transport from Earth and enable longer duration stays at Mars. For example, oxygen for life support and as an oxidizer for propulsion systems could be recovered from CO₂ gas in the atmosphere (10). Another example of ISRU includes the recovery of mission-enabling H₂O for life support and H for propulsion from hydrated minerals and/or shallow, near-surface ice.

Return of Martian surface samples to Earth could reduce the technical risk associated with each of these ISRU options. Atmospheric-based ISRU is the highest priority with the Mars human exploration architecture but both the mechanical and chemical properties of dust might interfere chemically with systems that extract O from CO₂ from the atmosphere (10). Thus, sample return and characterization of dust like that suspended in the atmosphere would be of high priority. Currently, seasonal cycles of the column abundance of dust (11) and average particle size throughout the column (12) are known with some fidelity. However the full particle size distribution and mechanical properties of the dust are unknown, and its composition is understood only approximately for major phases for dust in the atmosphere and mixed with coarse-grained soil. Also there is little information on minor and trace phases (e.g., 13).

The most definitive way to assess whether the martian dust would hinder extraction would be to test the ISRU with samples of dust returned from Mars or with high fidelity simulants designed based on analysis of returned dust.

An additional priority would be to return a sample of a hydrated mineral resource. Current orbital mapping reveals locations and some information on volume of mineral deposits with enhanced water content of up to about 8%, or ~5% higher than in background soils (14). The water occurs in a variety of mineral phases including phyllosilicates, sulfates, hydrated silica, and carbonates, sometimes in association with other hydrous

or hydroxylated phases. Some of the deposits (clays, carbonates) are chemically neutral whereas others are thought to be acidic (15). There is limited information on minor phases that could affect resource extraction only at one major deposit, e.g., at the Mars Exploration Rover (MER)/Opportunity landing site (13). The mechanical and geotechnical properties of hydrated mineral deposits are highly uncertain, again known in part only at one location (16), and the energy required to extract the H₂O is speculative. In situ investigations (for example, coring/drilling combined with mineralogical and elemental abundance measurements, differential scanning calorimetry / thermal analysis, evolved gas analysis, or gas chromatography / mass spectroscopy) could provide information on mechanical and geotechnical properties, energy requirements for resource extraction, and abundances of major and some minor mineral phases. A returned sample would provide comparable information on geotechnical properties and much more comprehensive information on the chemistry of the material. Given the variability of hydrated mineral resources, the most valuable samples related to ISRU would come from a site of potential human exploration.

Near-surface ice is another potential resource both for crew support and for hydrogen as a fuel. The sensitivity of ISRU of ice to factors such as fraction of ice present, the difficulty of mining ice and the effects of contaminants on extraction is unclear.

III. ATMOSPHERE

Although several issues related to the martian atmosphere must be resolved prior to sending humans to the martian surface, most of the atmospheric measurements needed to support aerocapture, Entry Descent and Landing (EDL) or a human mission to the surface of Mars (or to martian orbit) could be acquired without sample return. However, a sample of the dust from the atmosphere would improve radiative transfer calculations in numerical models, thereby enhancing our understanding of the atmospheric state. Despite any improvement based on sample return, atmospheric models will continue to have significant uncertainties until the vertical distribution and optical properties of the dust (and also water ice particles) are better determined. Therefore, although these measurements and samples have great scientific value, the information returned from a martian sample would not address the requirement to understand definitively the global atmosphere prior to any human missions.

IV. HUMAN FACTORS

As currently envisioned, the human exploration of the Martian surface would be a relatively long duration activity, lasting approximately 18 months (17). Several human health-related issues in addition to planetary protection (discussed above) would present risks to the crew and mitigations for these issues are still being

researched. One risk that would benefit from a returned sample is an understanding of the chemistry, electrical properties, morphology and biological hazards of dust, which has been distributed globally by the atmosphere.

Throughout a mission, it is anticipated that a crew would make numerous and extended forays into the region surrounding their landing site for exploration purposes. These forays would likely include small pressurized or unpressurized rovers and extravehicular activity (EVA) suits. The crew would be expected to experience prolonged exposure to martian surface and airborne materials, principally the globally distributed dust, which would inevitably make its way inside the EVA suits, small, pressurized rovers, and the primary surface habitat similar to what happened on Apollo landed missions. This exposure would include skin and eye contact as well as inhalation. Determining the potentially deleterious effects of this exposure and how to mitigate the effects would be important before committing a crew to such a mission (10).

There are several options for assessing the effects of dust exposure. The use of various reagents *in situ* is one such experiment, but a more comprehensive approach to the understanding of dust exposure would result from laboratory experiments on returned samples. The advantages of Earth-based laboratory measurements involve, for example, the use of complicated sample preparation techniques, exposure under different conditions, the use of multiple species.

V. SURFACE HAZARDS

As discussed in the Human Factors section, potential human exploration of the martian surface is currently envisioned to last approximately 18 months (17). During this time the crew would presumably be expected to make numerous traverses to locations surrounding their landing site, placing significant emphasis on the reliability and longevity of their equipment. This would be especially true of EVA suits and small pressurized or unpressurized rovers used to transport the crew and their equipment across 10s to 100s of kilometers of Martian terrain. Identifying and understanding surface hazards that could reduce the availability of this equipment or cause the crew to cut short their surface mission due to significantly degraded equipment would be important during the design process for these systems. Identifying hazards that could benefit from *in situ* measurements or returned samples from the Martian surface include chemical, physical (i.e., shape), and mechanical (e.g., adhesion) properties of dust and larger particulates likely to be found at any landing site (18). These properties must be characterized in both the nominal martian atmosphere and in an atmosphere typical of the crew's pressurized spaces, with higher humidity and oxygen content. In addition it would be desirable to identify any effects that

are the result of repeated transitions between these two atmospheres.

Evidence from the Viking landers and Mars Exploration Rovers indicate that material selection and design practices are adequate for design of functionally equivalent robotic systems to support human surface missions of the durations envisioned. There are additional systems peculiar to supporting human crews that are not typically used for robotic missions and that could benefit from *in situ* measurements designed to facilitate development of appropriate simulants or from *in situ* exposure to observe environmental effects. These include materials used to seal airlocks and EVA suits, for rotating joints in EVA suits, and EVA garment material. Filters would also be used as part of the air revitalization systems inside pressurized compartments. Inevitably, martian dust and particulates would affect these filters. Proper procedures would enable a team to back flush or predict the replacement period, keeping the system working properly for the entire duration of a surface mission. The return of a dust sample would enable proper filter design and cleaning procedures.

Another surface hazard that would, in part, be the result of any human activity is the blast ejecta from the landers used to deliver a human crew and their equipment. The current approach envisioned for surface exploration by human crews involves pre-deploying a portion of the surface exploration equipment on one or more landers (17). The crew would arrive many months later after some or all of this pre-deployed equipment has been put into operation on the surface. The crew should land as close as possible to this pre-deployed equipment. However, the lander's terminal descent engines would likely excavate a crater under each engine, possibly making the surface unstable and launching the excavated material on high speed, low angle ballistic trajectories that could cause significant impact damage to nearby equipment (see Beaty et al., 2005 for a partial summary). Physical and computer based simulations of these events have been made, but data from Mars is required to calibrate and validate these simulation results. To satisfy this requirement, post-landing imagery of the area under descent engine(s) of future landers would provide some useful validation data. A more complete data set would require direct measurement of the surface material's physical characteristics, which should be measured in a vertical profile to a depth of at least one meter. *In situ* measurements of this vertical column could be sufficient but return of a core sample could enhance the understanding of martian material properties, particularly their variability with depth, and improve models used for system design and testing.

V. CONCLUSIONS

The robotic return of samples from Mars would serve two compelling and complementary goals by 1)

obtaining a quantum increase in our scientific understanding of Mars that cannot be achieved by other means, and 2) obtaining information essential to the health and well-being of potential human explorers and for protection of Earth from any biological contaminants. The timing of any MSR mission is critical: scientifically we are ready now to take this step as prior and current robotic missions have paved the way for identifying high potential MSR sites. Given MSR lead-time requirements on technology and development, the potential return of samples should be targeted for the 2020's. MSR must be done sufficiently far ahead of any human missions to enable essential precautions to be built in to assure astronaut health and safety. The lead-time for samples to be useful in human exploration planning is measured in decades. Given the current goal of humans to Mars in the 2030's, the conclusion is that MSR must also occur in the 2020's. This fortuitous confluence of timing for scientific and human exploration needs, and given the long development time-scale for MSR, argues that we must escalate serious planning for the MSR campaign now.

The most important unknown with respect to Mars is whether there is any indigenous life on the planet and, if so, whether it would present a hazard to a crew and the Earth's biota. Definitive life detection and hazard assessment require analysis of samples returned to Earth. Returned samples would be comprehensively tested by a wide array of techniques in the world's most sophisticated laboratories. If life were found then elaborate procedures would be needed to protect a crew and Earth from possible adverse effects. With extended stays on the surface a crew would inevitably be exposed to martian materials, so regardless of whether martian life exists, we need to consider whether martian materials could be toxic. The ever-present dust might also have corrosive effects on engineering elements such as seals and filters. With samples here on Earth, any potential toxic and corrosive effects could be tested on actual samples. Finally, martian resources, such as oxygen from the atmosphere and water from minerals and ice, may be required to implement any human missions. Having samples from the target resources will enable the practicalities of such resource extraction to be confidently assessed.

Despite the best efforts at containment, human missions would likely contaminate the planet's surface with terrestrial organisms that would be dispersed about the planet and could find their way into potentially habitable regions, potentially masking or even destroying any indigenous life or pre-biotic chemistry. Return of samples prior to any human mission would enable assessment of the evidence of any past or present life before any such evidence is compromised.

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